BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 10002

SUBJECT: Plane-Change Penalty for Unscheduled Abort from the Lunar Surface - Case 105-4

DATE: October 1, 1970

FROM: A. L. Schreiber

ABSTRACT

Unscheduled abort from the lunar surface to target-orbits whose planes do not contain the launch site is examined. Consequent plane-change penalties are presented graphically, along with time until minimum (or zero) penalty, as a function of target-orbit inclination and the relative position of the launch site. The variation of this penalty during a lunar month is also presented for several latitudes and target-orbit inclinations.

For the entire range of landing-site latitudes, and for specific target orbits, two single-impulse plane-change ΔV's are determined -- the maximum abort plane-change and the minimum (may be zero) descent plane-change. (The abort is assumed unscheduled and worst case, the descent is assumed scheduled and optimal.) The range of latitudes and the percentage of the lunar surface accessible are presented as functions of these two plane-change ΔV's and their sum. The results are extended by using a three-impulse plane-change with a twelve-hour constraint on the maneuver. The three-impulse maneuver shows a substantial improvement for large plane-changes.

These graphs show the relative superiority of polar and equatorial target-orbits for high and low surface latitudes respectively. No such favorable correspondence exists between middle latitudes and middle-inclination target-orbits. For example, a 45° latitude site may require a 7550 ft/sec single-impulse plane-change to get into a 45° inclination orbit, but only 4100 ft/sec to get into an equatorial or polar orbit.

(NASA-CR-113927) PLANE-CHANGE PENALTY FOR UNSCHEDULED ABORT FROM THE LUNAR SURFACE (Bellcomm, Inc.) 36 p

N79-71902

Unclas
00/13 11896

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 10002

SUBJECT: Plane-Change Penalty for Unscheduled Abort from the Lunar Surface - Case 105-4

DATE: October 1, 1970

FROM: A. L. Schreiber

MEMORANDUM FOR FILE

INTRODUCTION

Advanced lunar missions may involve stay times on the lunar surface of weeks or months. Consequently, when we consider the possibility of an abort from the lunar surface to an orbiting vehicle or lunar orbit station, we must consider that, in general, the launch site will not be in the target-orbit plane. If the abort cannot be delayed until the launch site rotates into the orbit plane, a substantial ΔV penalty may be incurred in order to put the abort vehicle into the plane of the target-orbit.

For this study, a 60 NM circular orbit was selected for the target-orbit and a 60 NM circular orbit was also selected as the initial orbit for a vehicle aborting from the surface. Two maneuvers were considered -- a single-impulse and a three-impulse plane-change. Since the relative contribution of the lunar rotation to launch requirements is negligible (equatorial rotational velocity $\approx$ 15 ft/sec) launch ΔV is treated as a constant and most ΔV's discussed in the rest of this memo are plane-change ΔV's. It should be borne in mind that ascent and descent characteristic velocities and any phasing ΔV's are to be added to plane-change ΔV's, as appropriate in considering overall requirements.

ANALYSIS

In general, the required plane-change will vary with target-orbit inclination, launch site latitude, and time. We first consider the single-impulse plane-change from one circular orbit to the other.

Let

ι = inclination of the station-orbit

ϕ = latitude of the launch site

τ = days from minimum plane-change

V_c = circular velocity at 60 NM (5339 ft/sec)

λ = longitudinal angle from the ascending node of the station-orbit to the launch site, + in the easterly direction, - to the west

θ = minimal arc on the lunar surface from the launch site to the station-orbit trace

δ = angle between two velocity vectors

Whatever azimuth is selected for the launch, the abort-orbit and target-orbit will have two points of intersection, 180° apart. At each intersection, as in Figure 1, each orbital velocity vector has the magnitude V_c, and the angle between them is the same at both intersections. If that angle, $\delta > 90°$, we could have launched in the opposite direction with essentially the same launch ΔV, changing δ to its supplement, thereby reducing the plane-change penalty. There is therefore never a need to consider an abort plane-change >90°. The magnitude of the difference between the two velocity vectors is given by

$$(\Delta V)^2 = 2V_c^2 - 2V_c^2 \cos \delta$$
$$\Delta V = 2V_c \sin \frac{\delta}{2} \qquad (1)$$

To minimize ΔV for a given configuration of launch site and station orbit at a given time we can see from (1) that we wish to minimize the magnitude of δ. In Figure 2 we have the target-orbit trace PI, an arbitrary abort-orbit trace LI, and the minimal arc from the launch site L perpendicular to the target orbit trace at P. From the right-triangle relationships in IPL we can see that $\tan LIP = \frac{\tan PL}{\sin IP}$. LIP is the angle δ in (1), and, since PL is constant, the minimum of δ occurs when IP = 90°. With IP and IPL both 90°, we have a two-right-angle triangle. Both PLI and LI are also 90°, and the arc LP which we have called θ has the same value as the intercept angle δ. A geometrical symmetry is now evident as can be seen in Figure 3. The two arcs IJ are great semi-circles and the arc θ is their perpendicular bisector at L and at P. Thus the problem of finding the minimum ΔV (minimized over launch azimuth, not time) depends on finding θ, the arc length from the launch site to the target-orbit plane, and (1) gives us

$$\Delta V = 2V_c \sin \frac{\theta}{2} \tag{2}$$

The symmetry in the geometry of the two orbit traces and the negligible rotational velocity of the lunar surface tell us that in computing plane-change requirements we do not need to concern ourselves with the direction of rotation in the orbits. Consequently, we will consider only posigrade target-orbits.

In Figure 4 we have a typical configuration. A is the launch site, B is the position the launch site will occupy when it rotates into the target-orbit plane. N is the north pole and E is the ascending node of the target-orbit. In order to determine the plane-change ΔV required, we must compute the arc AF which is perpendicular to the target-orbit trace.

Triangle DCE is a right triangle, and

$$CE = -\lambda$$

$$CED = \iota,$$

and from right triangle relationships

$$\sin CE = \cot CED \tan DC$$

or

$$\sin (-\lambda) = \cot \iota \tan DC$$

or

$$DC = \arctan [\sin(-\lambda) \tan \iota]. \tag{3}$$

Also from right triangle relationships

$$\cos EDC = \cos CE \sin CED$$

or

$$\cos EDC = \cos (\pm\lambda) \sin \iota. \tag{4}$$

AFD is also a right triangle and

$$FDA \equiv EDC. \tag{5}$$

From right triangle relationships,

$$\sin AF = \sin FDA \sin DA \tag{6}$$

Noting also that

$$DA = DC + CA \tag{7}$$

$$CA = \phi \tag{8}$$

$$AF \equiv \theta, \tag{9}$$

and substituting (3), (4), (5), (7), (8), (9) into (6) and simplifying we have

$$\sin\theta = \sqrt{1-\cos^2\lambda\sin^2\iota}\ \ \sin[\phi-\arctan(\sin\lambda\tan\iota)]. \tag{10}$$

We may then use (10) and (2) to compute the single-impulse plane-change ΔV for an unscheduled abort.

We next wish to compute τ, the time from minimum ΔV. In the case shown in Figure 4, that minimum will be zero, and will occur when the launch site will have moved from A to B. The angular equivalent of τ is ANB.

Since NE and NG are meridians of longitude and EG is the equator, the angle ENB will have the same value as the arc EG. The triangle BGE is a right triangle and

$$GEB = \iota$$

$$BG = \phi$$

so

$$\sin EG = \frac{\tan \phi}{\tan \iota}$$

or

$$ENB = \arcsin\left(\frac{\tan \phi}{\tan \iota}\right) \tag{11}$$

We now have the two components of the angular equivalent of time, $-\lambda$ and ENB, and the lunar period of 27.322 days is the time equivalent of 360°. We wish to have τ increasing with time. To accomplish this with the launch site approaching zero ΔV as in Figure 4, τ would be negative. So we have

$$\tau = - \frac{27.322}{360°} \cdot (\text{ENB}-\lambda)$$

or

$$\tau = \frac{27.322}{360°} \left[\lambda - \arcsin\left(\frac{\tan\phi}{\tan\iota}\right)\right] \tag{12}$$

and we can compute τ with (12) as long as $|\phi| \leq \iota$.

As we can see in Figure 4, if $\phi > \iota$, the launch site A would never rotate into the plane of the target-orbit. It is also obvious in this case that the arc θ reaches its minimum when the launch site has rotated 90° (longitudinal angle) beyond the ascending node of the target-orbit, and that this minimum is greater than zero. The computation of τ is simpler in this case. Analogous to (12),

$$\tau = \frac{27.322}{360°} (\lambda - 90°) \qquad (\text{for } \phi \geq \iota) \tag{13}$$

Figure 4 shows the launch site A at a latitude $\phi < \iota$, and λ in the range, $-90° < \lambda < 0$. It can be shown that for all possibilities in the ranges $-90° \leq \lambda \leq 90°$ and $0 \leq \phi \leq 90°$, equations (10) and (2) may still be used to compute a single-impulse ΔV, and either (13) or (12) used for τ as ϕ is greater of less than ι. This still covers only one quadrant of the lunar surface. However, for any point on the lunar surface which is outside of the quadrant analyzed, we can find a corresponding point <u>inside</u> that quadrant which has the identical geometrical relationship to the parking orbit as the point <u>outside</u> does. Thus we have all we need to compute a single-impulse ΔV and τ for the entire lunar surface and for any inclination target-orbit.

The total ΔV required to effect a given plane-change can be reduced below that required for a single impulse by using multiple impulse maneuvers. No general n-impulse optimization was performed for this study, but a family of three-impulse maneuvers was examined. These maneuvers consisted of ellipticizing the initial circular abort-orbit, rotating the orbital plane at apoapsis, and re-circularizing at periapsis.

The period of the intermediate ellipse was varied from 3 hours to 24 hours giving the family of curves in Figure 5. The parabola at 4425 ft/sec ($\Delta V_{escape} = V_c\ (\sqrt{2} - 1)$) is a theoretical bound on the family of ellipses. It can be seen from Figure 5 that there is some value of the required plane-change, below which the single-impulse is the better maneuver. We can find this critical value of θ by equating the single-impulse ΔV and the sum of the three-impulse ΔV's and examining θ as the ellipticizing ΔV approaches zero.

Let

r_p = periapsis radius

a = semi-major axis

The single-impulse ΔV is $2V_c \sin\frac{\theta}{2}$ as given by (2); the ellipticizing and recircularizing ΔV's are each $V_c\sqrt{2 - \frac{r_p}{a}} - V_c$; and the rotational ΔV at apoapsis is $\frac{2V_c r_p}{2a - r_p}\sqrt{2 - \frac{r_p}{a}}\sin\frac{\theta}{2}$.

This gives us

$$2V_c \sin\frac{\theta}{2} = 2\left[V_c\sqrt{2 - \frac{r_p}{a}} - V_c\right] +$$

$$\frac{2V_c r_p}{2a - r_p}\sqrt{2 - \frac{r_p}{a}}\sin\frac{\theta}{2}$$

which simplifies to

$$\sin\frac{\theta}{2} = \frac{\sqrt{2 - \frac{r_p}{a}} - 1}{1 - \frac{r_p\sqrt{2 - \frac{r_p}{a}}}{2a - r_p}}$$

As the ellipticizing ΔV approaches 0, a approaches r_p, and by applying L'Hospital's rule, we get

$$\lim_{a \to r_p} \theta = 2 \arcsin \frac{1}{3} \approx 38°$$

The corresponding value of ΔV from (2) is 3559 ft/sec, i.e., single-impulse plane-change ΔV's >3559 ft/sec can be reduced by using a three-impulse maneuver.

GRAPHICAL PRESENTATION OF τ and ΔV

Figures 6 and 7 show τ and single-impulse ΔV contours for the entire lunar surface for target-orbits of 30° and 60° inclination respectively. Note that the line $\tau = 0$ is also the target-orbit trace and the $\Delta V = 0$ contour. The ΔV contours 5339 on Figure 6 and 2764 on Figure 7 also identify the values of ΔV at the lunar poles. These are of course independent of time. Their values are determined by substituting $\theta = 90° - \iota$ into (2) giving $\Delta V_{polar} = V_c \sqrt{2(1-\sin \iota)}$.

The maximum value that a single-impulse ΔV can reach is independent of target-orbit inclination, and occurs with a 90° plane-change. Consequently, by substituting θ = 90° into (2), we get $\Delta V_{max} = \sqrt{2}\, V_c$ = 7550 ft/sec. This occurs at two points, $(\lambda,\phi) = (-90°, 90°-\iota)$ and $(+90°, -90° +\iota)$ which are the poles of the target-orbit. Note also that τ is signed. Negative values indicate that we are approaching minimum ΔV, positive values indicate days beyond the minimum. As we pass through $\lambda = \pm 90°$, both the optimal launch direction and the sign of τ reverse.

When $\iota = 0°$, ΔV is independent of time and is a function only of latitude. As can be seen from (10), when $\iota = 0°$, $\theta = \phi$. Figure 8 shows ΔV as a function of ϕ for $\iota = 0°$. To show the improvement that the three-impulse maneuver can effect for plane-changes > 38°, a 12-hour constraint was arbitrarily selected and the results plotted on Figure 8 as the dotted extension of the single-impulse ΔV curve.

The polar target-orbit ($\iota = 90°$) introduces a symmetry in the magnitude of ΔV about the line $\lambda = 0$. This can best be seen by visualizing the orbit plane perpendicular to the lunar equator with the ascending node defining $\lambda = 0$. It can also be seen by examining (10) and (2). The magnitudes of both factors of (10) are, in general, asymmetric functions of λ. However, when $\iota = 90°$, they are both symmetric functions of λ. This establishes the magnitude of θ as a symmetric function of λ, and (2) shows that this symmetry extends to ΔV. When $\iota = 90°$ we can see in (12) that τ is directly proportional to λ. These considerations permit the representation of ΔV in Figure 9 with λ and τ merely as 2 different scales on the abscissa. In Figure 9, λ ranges from 0° to 180° and ϕ from 0° to 90°. With a change of sign of λ, there is no change in ΔV, only the sign of τ changes. ΔV and τ are unchanged with a change in sign of ϕ.

Figures 6, 7, and 9 all refer to single-impulse plane-changes. However, the regions in which ΔV can be reduced by using the three-impulse maneuver previously described have been indicated. ΔV contours for 3559 ft/sec have been plotted with perpendicular hatch markings. The directions in which these markings point indicate the regions where ΔV can be reduced by using the family of three-impulse curves in Figure 5.

ABORT ΔV VARIATION WITH TIME

Figure 10-12 show time-histories of abort ΔV for several latitudes and for target-orbit inclinations of 30°, 60°, and 90° respectively. The solid lines indicate single-impulse values, and the dashed extensions indicate the values derived from the three-impulse maneuver with the 12-hour constraint.

DESCENT PLANE-CHANGE PENALTY

We next consider a single-stage vehicle which descends to the lunar surface from a lunar orbit space station and then must ascend to that same orbit. If the magnitude of the latitude of the landing site is greater than the inclination of the station-orbit, there will be a descent plane-change penalty to consider in addition to the unscheduled abort plane-change penalty (plus the constant in-plane descent and ascent requirements). We assume that the descent maneuver is scheduled, and that the plane change is minimal and is zero if $\phi \leq \iota$.

Two great circles achieve their maximum separation midway between their intersections, and the arc length of this separation has the same value as the angle between them at the intersections. Therefore, the target-orbit will reach its highest latitude 90° beyond its ascending node, and the value of the highest latitude will be ι, the inclination of the target-orbit. This can be seen in Figure 13. When $\phi > \iota$, a descent plane-change will be required. The required separation of descent and target-orbits in this case is $\phi - \iota$ and to achieve it with a minimal plane-change, the impulse must be given 90° before the maximum latitude is reached, i.e., at the ascending node. Similarly to the development of (2) the descent plane-change is then given by

$$\Delta V = 2V_c \sin \frac{\phi - \iota}{2}$$

The curves in Figure 5 could also be used to determine a reduced three-impulse ΔV if a descent plane-change >38° were desired.

MAXIMUM VALUE OF ΔV

To determine the maximum values for single-impulse unscheduled abort plane-change ΔV, we re-examine equations (2) and (10). Since we need never consider θ outside of the range (0°, 90°), we can see from (2) that ΔV reaches a maximum when θ reaches a maximum. This will occur when the right hand member of (10) reaches maximum magnitude. For any values of ϕ and ι, the first factor of (10) attains its maximum when $\lambda = \pm 90°$, and the second factor attains its maximum $\lambda = -90°$. So $\sin\theta$, and ΔV are maximal when $\lambda = -90°$.

When $\lambda = -90°$,

$$\sin\theta = \sin[\phi + \arctan(\tan \iota)]$$

$$\theta = \phi + \iota. \tag{16}$$

So, for a given ι, the maximum abort ΔV will occur when $\lambda = -90°$, $\theta = 90°$ and $\phi = 90° - \iota$. This point is a pole of the target-orbit. For latitudes other than $\phi = 90° - \iota$, the maximum abort ΔV for that latitude will be less severe, and is obtained by substituting (16) into (2) giving

$$\Delta V = 2V_c \sin \frac{\phi+\iota}{2} \tag{17}$$

When $\phi > (90° - \iota)$, $(\phi + \iota) > 90°$, which would mean using (17) with a plane-change greater than 90°. However, it was established in developing (1) that a plane-change >90° is never necessary. We simply reverse the direction of the launch. This gives us an intercept angle which is the supplement of the original. So in computing with (17) we use $\phi + \iota$ or $180° - (\phi + \iota)$, whichever is the smaller. Using (17) for computation of the maximum abort plane-change ΔV and (15) for the descent plane-change ΔV we have in Figures 14-21 both ascent and descent plane-change ΔV's and their totals required for a single-stage vehicle descending from and ascending to the same target-orbit. The solid lines indicate values derived from single-impulse ΔV's; the dashed extensions are from three-impulse maneuvers with a 12-hour constraint.

PORTIONS OF SURFACE ACCESSIBLE

Figures 14-21 show the relationship between two plane-change ΔV's and latitude. The first ΔV is the plane-change for an unscheduled abort from the lunar surface. It is a worst case value and is given by (17). The second ΔV is for a descent plane-change. It relates to a scheduled maneuver; it is the optimum value within the given constraints; and it is zero for all values of $\phi \leq \iota$. The sum of the two ΔV's is presented and the sum can be used to relate a given total plane-change ΔV capability to accessibility of latitudinal zones on the lunar surface. The solid lines represent single-impulse maneuvers, and the dashed extensions represent three-impulse maneuvers with a twelve-hour constraint.

For example, in Figure 19 with $\iota = 70°$, a total single-impulse plane-change capability of 5000 ft/sec would allow us to reach latitudes from 54° to 90°. A capability of 7000 ft/sec would allow us to reach two zones -- latitudes from 0° to 12° and 28° to 90°.

The fractions of the lunar surface in the accessible zones as just described have been used to compute the curves in Figures 22 and 23. These present percentage of lunar surface accessible as a function of total plane-change ΔV capability for station-orbit inclinations from 0° to 90°.

CONCLUSIONS

As can be seen on Figures 6 through 9, the maximum single-impulse abort plane-change ΔV ever required is 7550 ft/sec. This is a 90° plane-change, and regardless of station-orbit inclination, there are always two such points on the lunar surface. They are the two poles of the target-orbit trace.

For plane-changes <38°, there is no point in using the three-impulse maneuver. However, as the plane-change requirement increases beyond 38°, as could occur in an unscheduled abort, the usefulness of the three-impulse maneuver increases rapidly -- particularly as more time is allowed for the maneuver.

Within the context of Figures 14 through 23 (unscheduled abort ΔV plus landing plane-change ΔV) there is no good "universal" station-orbit. The low latitudes are best served by a low-inclination or an equatorial station-orbit since the maximum abort ΔV increases as station-orbit inclination is increased. The high latitudes, on the other hand, show a steadily decreasing total ΔV requirement as station-orbit inclination is increased to 90°.

The middle latitudes and orbits present a different situation. For example, a 45° latitude site could require a 7550 ft/sec single-impulse plane-change to get into a 45° inclination orbit. The maximum abort ΔV decreases from 7550 ft/sec to 4100 ft/sec as the station-orbit inclination is either lowered to 0° or increased to 90°. The equatorial orbit, however, imposes a descent plane-change requirement of an additional 4100 ft/sec making a polar orbit a better choice for a 45° latitude site.

For a plane-change ΔV capability of somewhat less than 5000 ft/sec the entire lunar surface is available to high inclination ($\sim$ 60-90°) orbits if three-impulse maneuvers are used.

ACKNOWLEDGEMENT

The writer wishes to acknowledge the help of Miss Mary C. Harris who performed many of the computations and plotted all the graphs in this memo.

A. L. Schreiber

A. L. Schreiber

1013-ALS-klm

Attachments
Figures 1-23

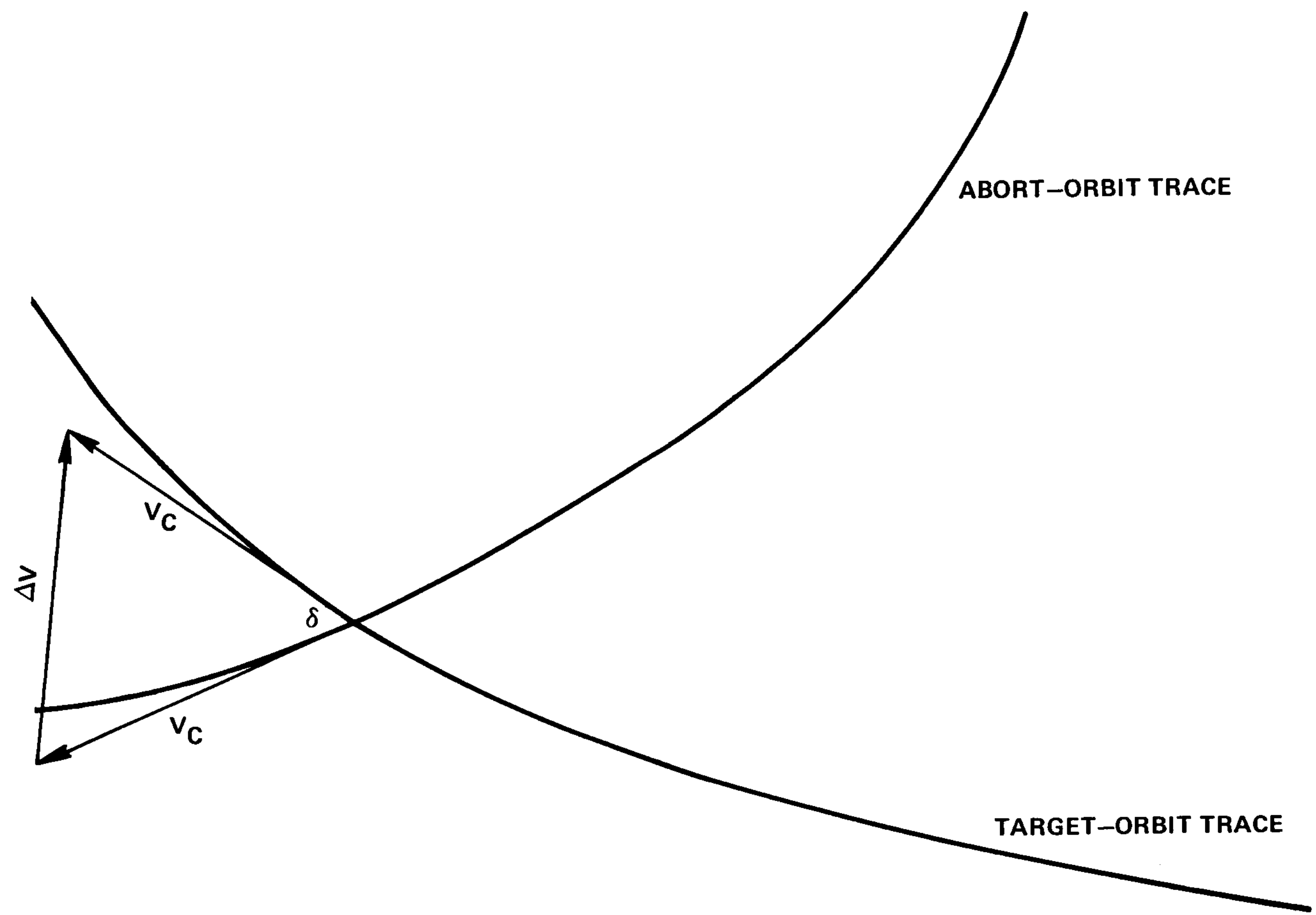


FIGURE 1

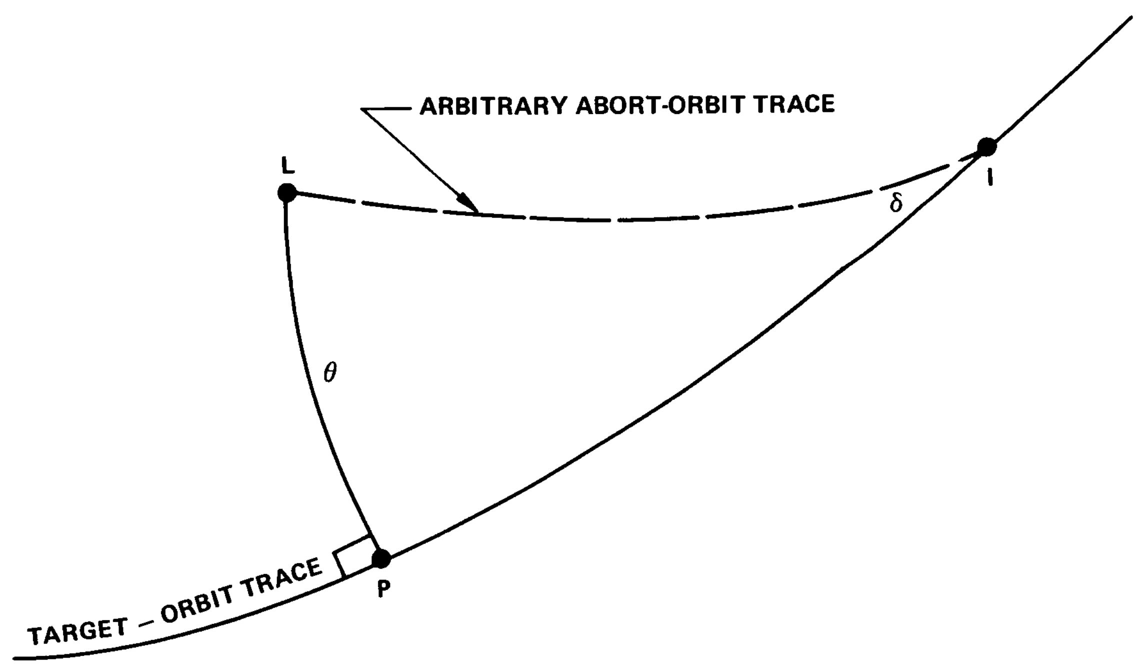


FIGURE 2

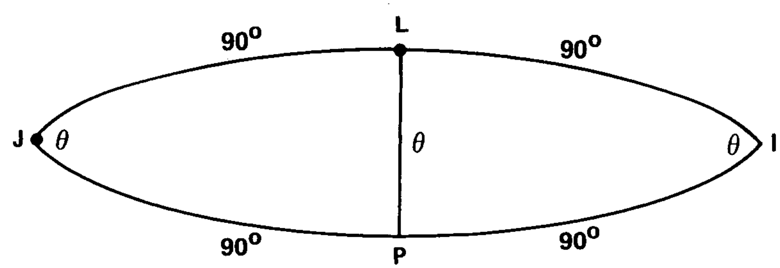


FIGURE 3

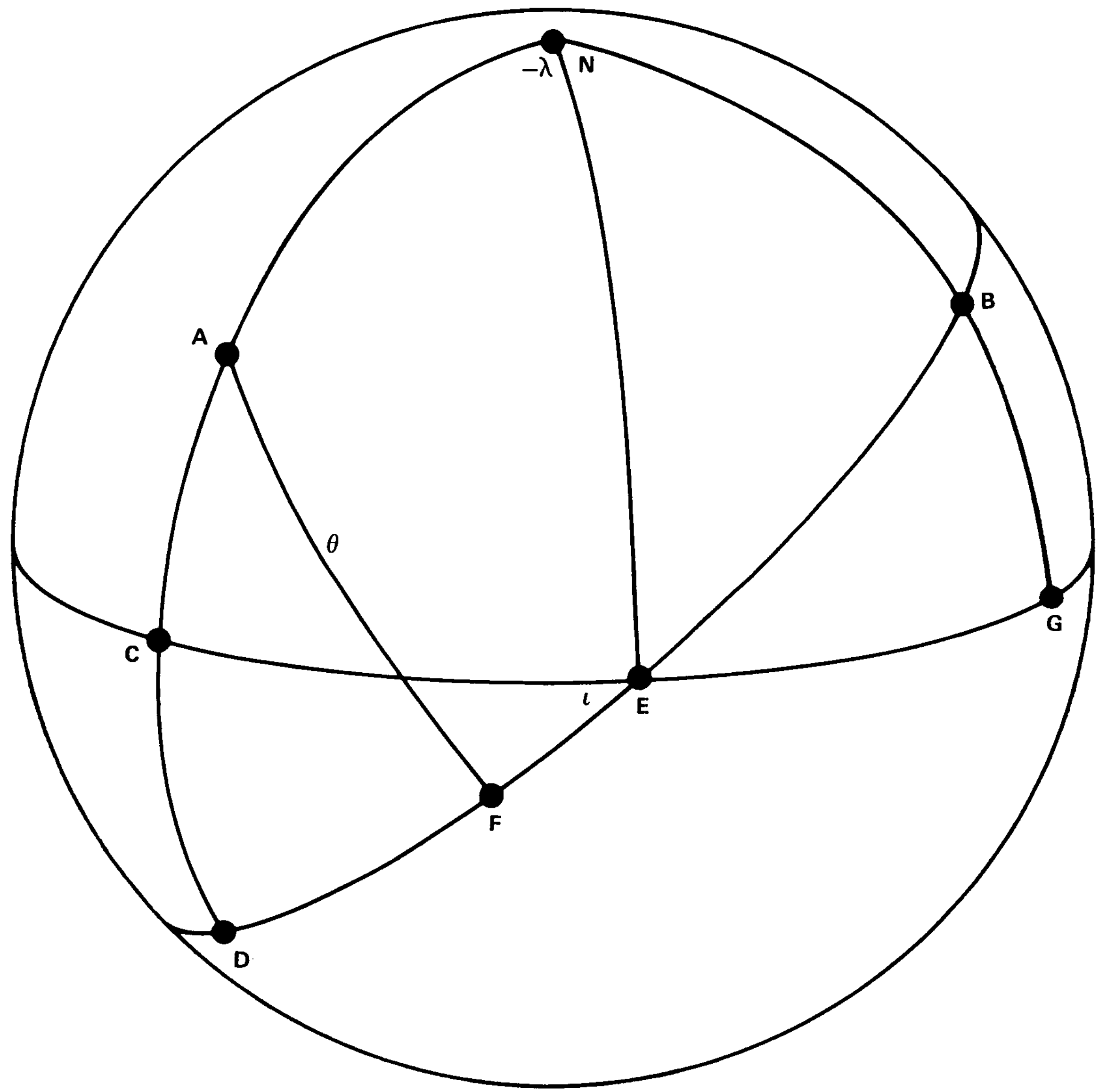


FIGURE 4

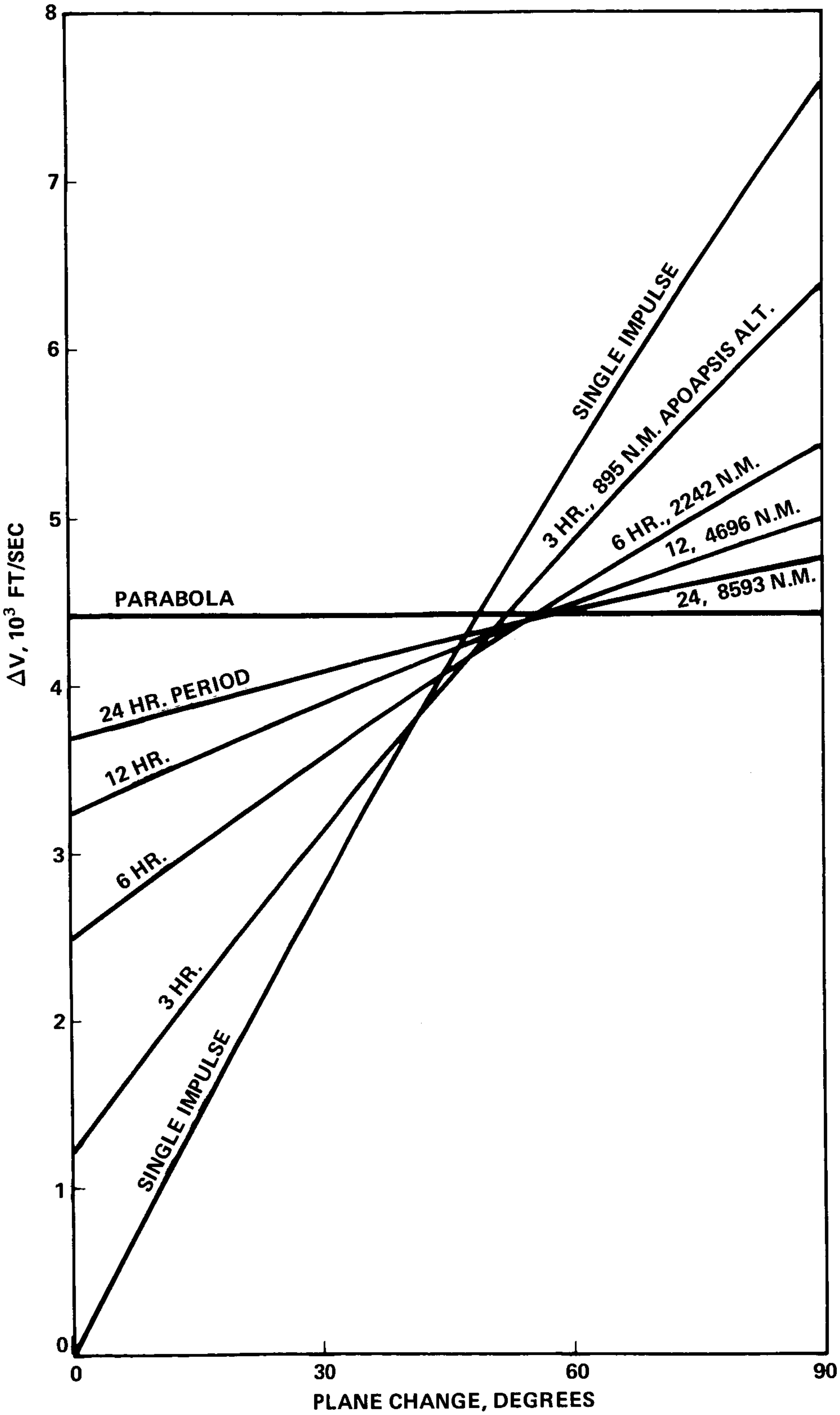


FIGURE 5
3-IMPULSE PLANE CHANGES

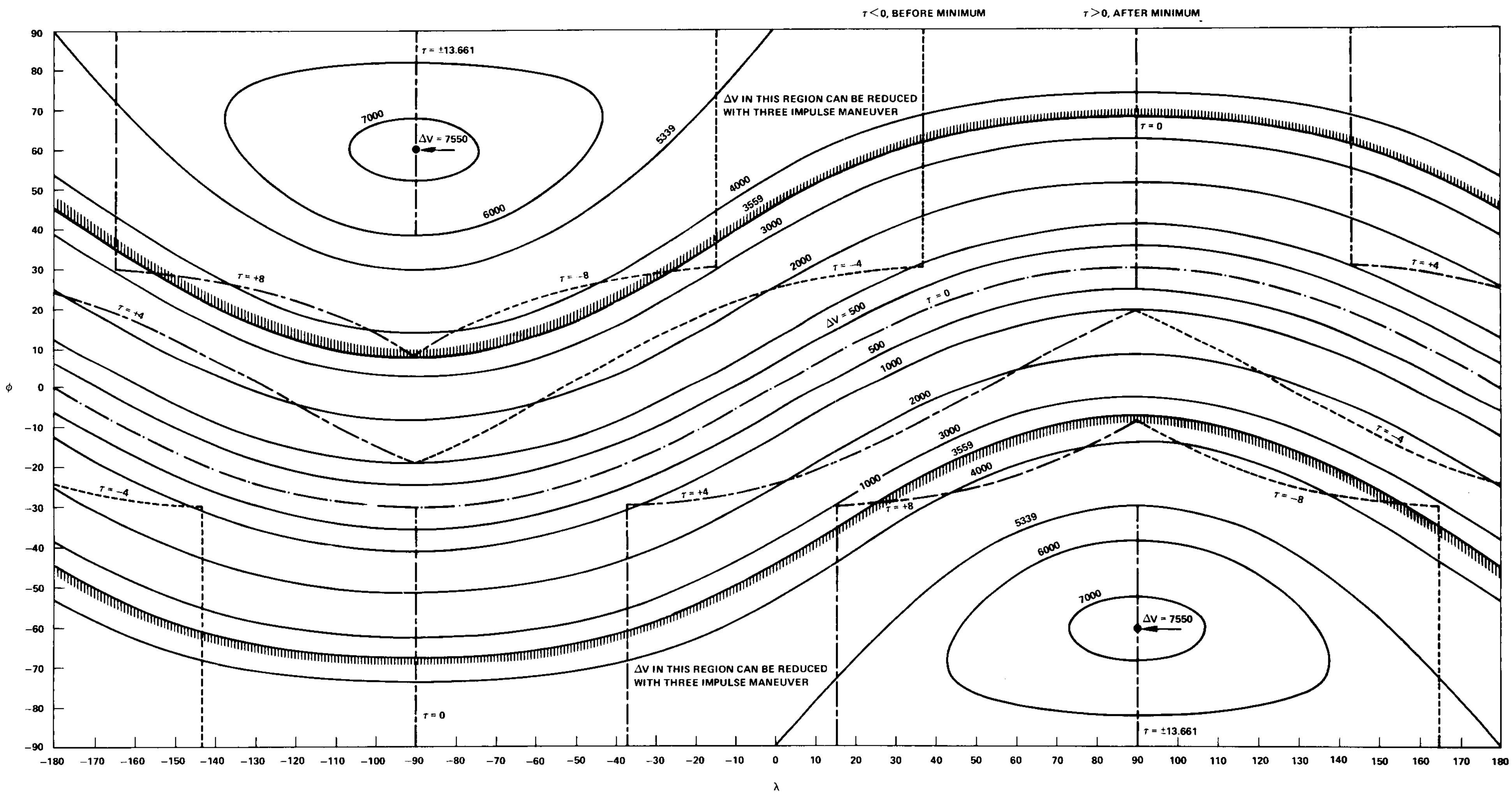


FIGURE 6 ABORT PLANE-CHANGE ΔV & TIME FROM MINIMUM ΔV
TARGET ORBIT INCLINATION = 30°

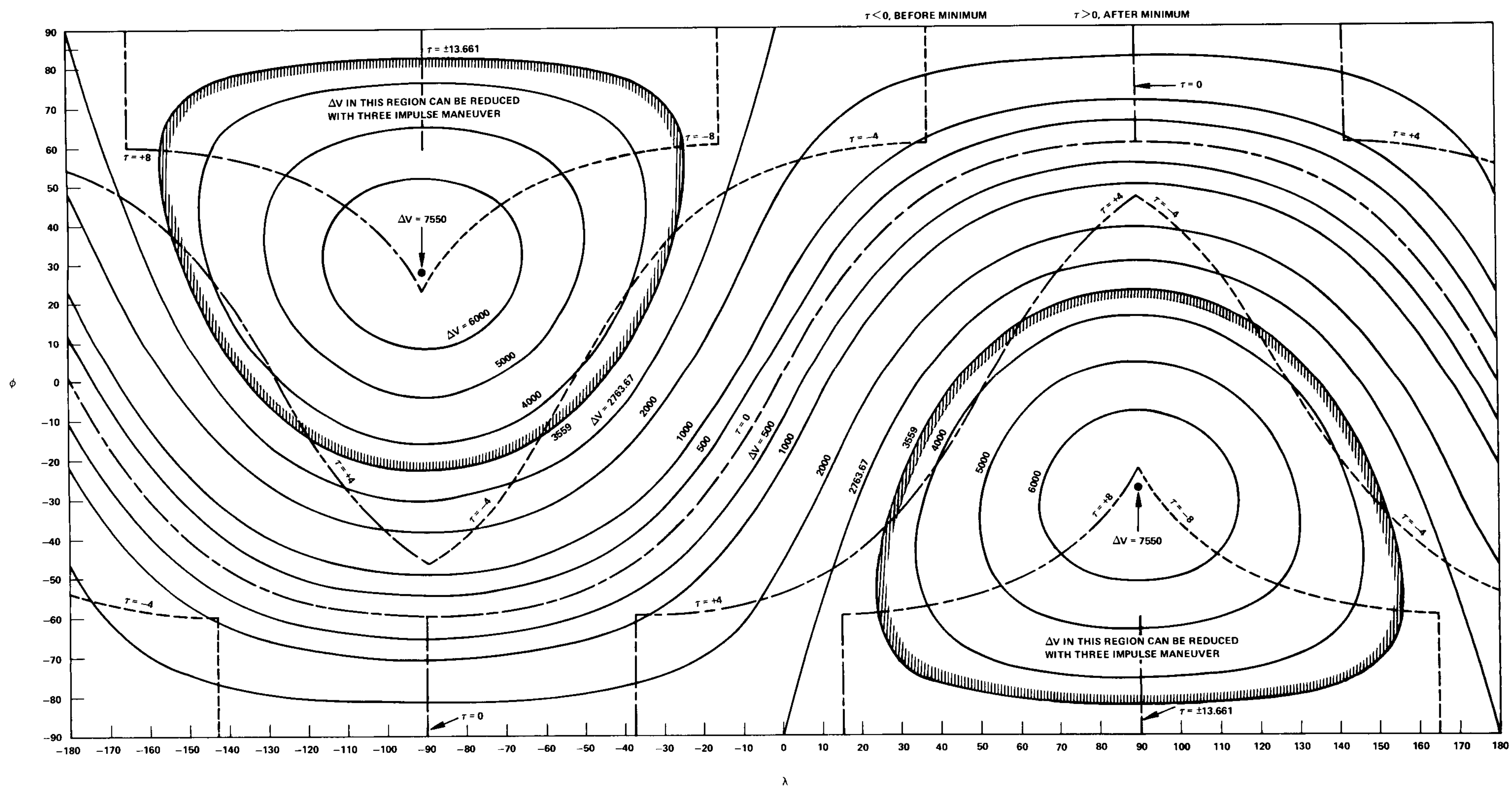


FIGURE 7 ABORT PLANE-CHANGE ΔV & TIME FROM MINIMUM ΔV
TARGET–ORBIT INCLINATION = 60°

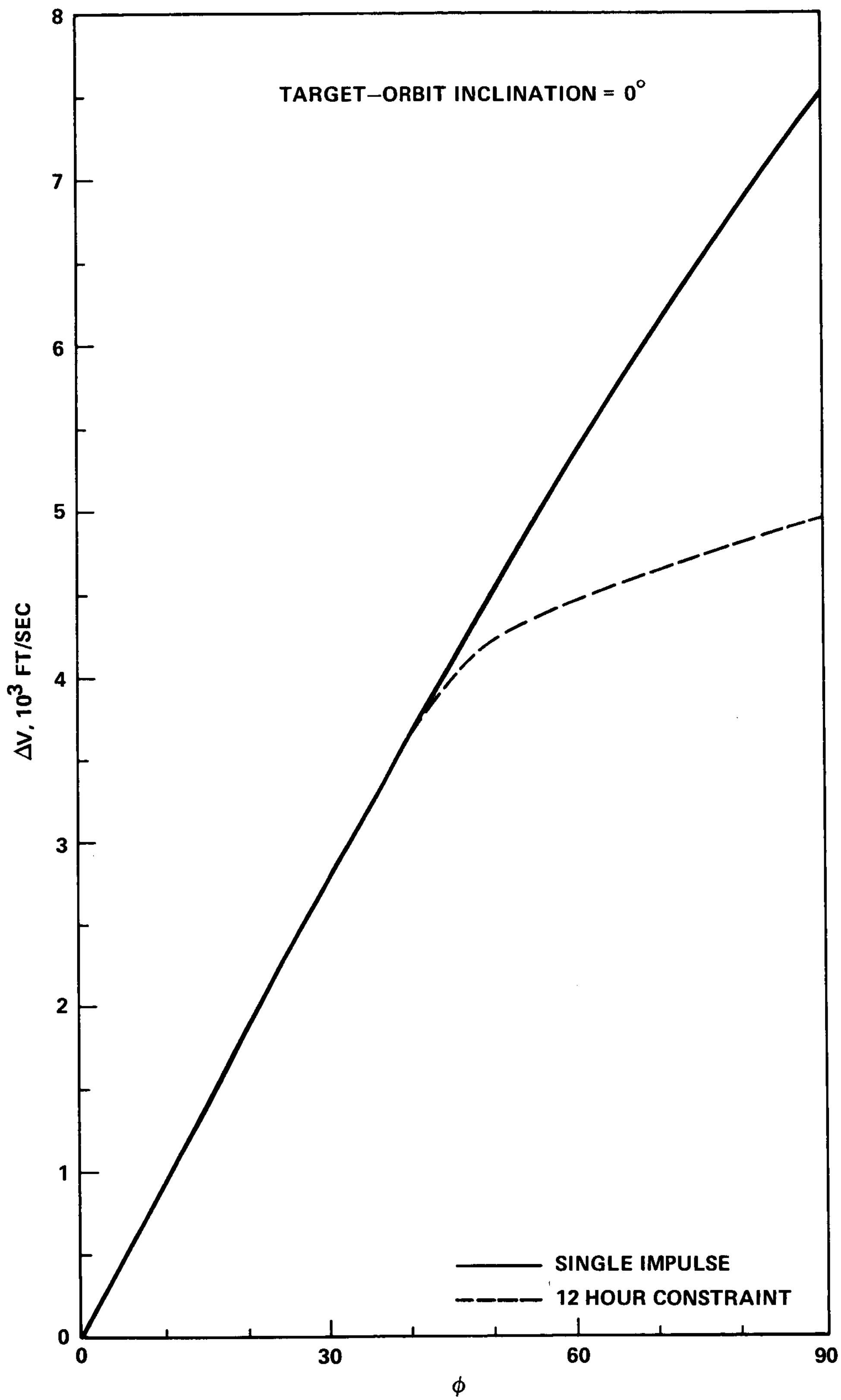


FIGURE 8 ABORT PLANE-CHANGE ΔV

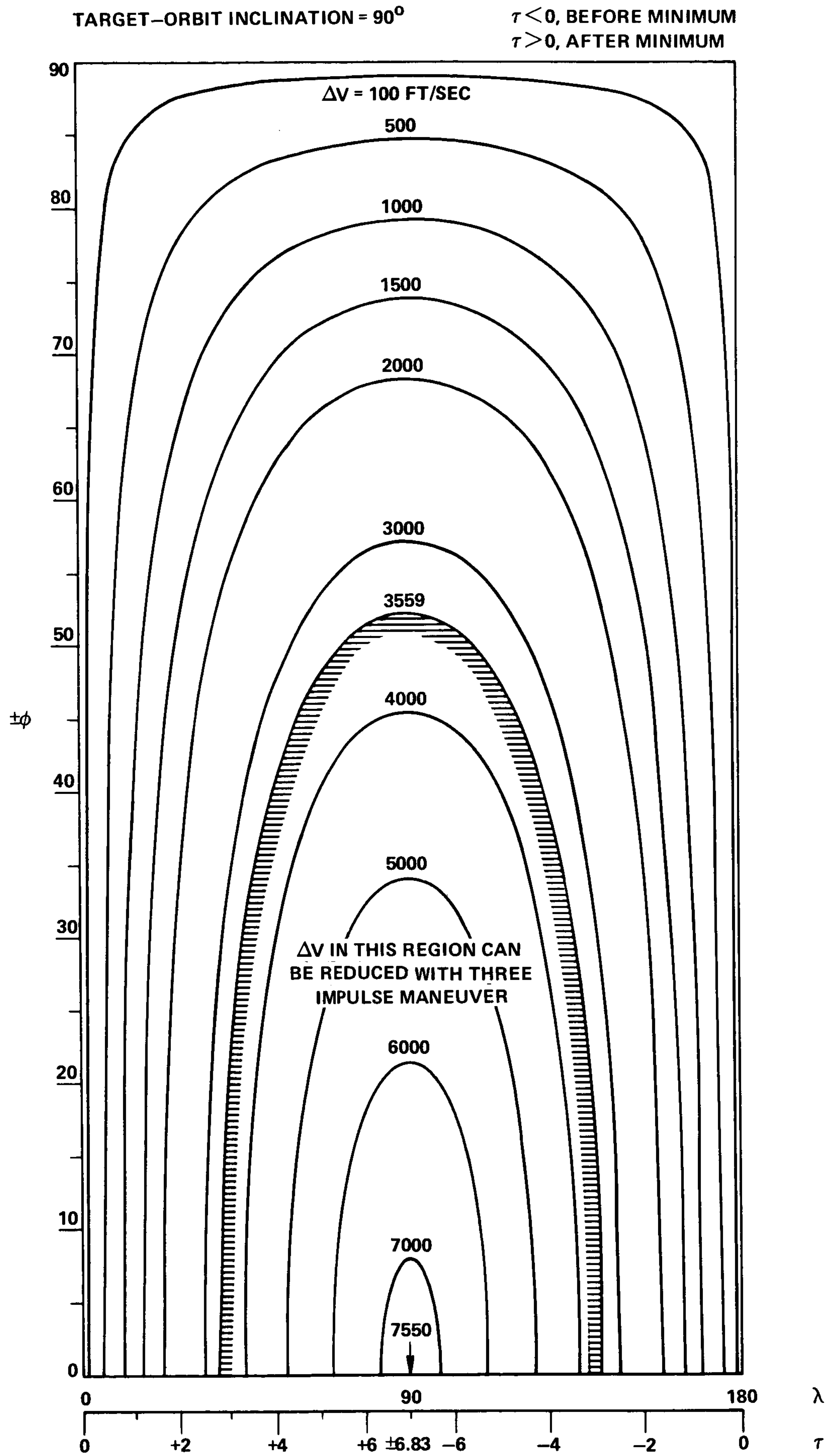


FIGURE 9 ABORT PLANE-CHANGE ΔV & TIME FROM MINIMUM ΔV

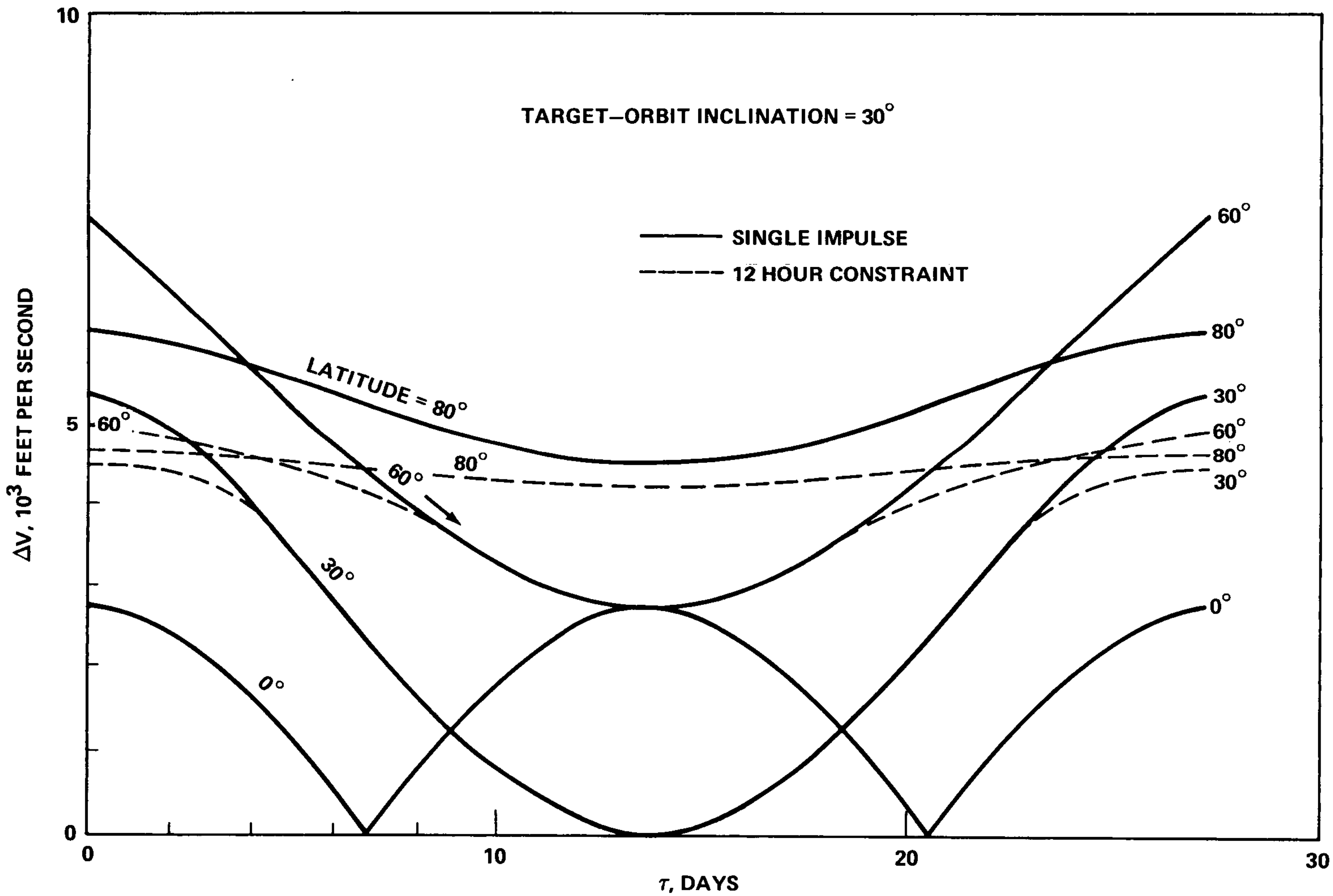


FIGURE 10 HISTORY OF ABORT PLANE-CHANGE ΔV

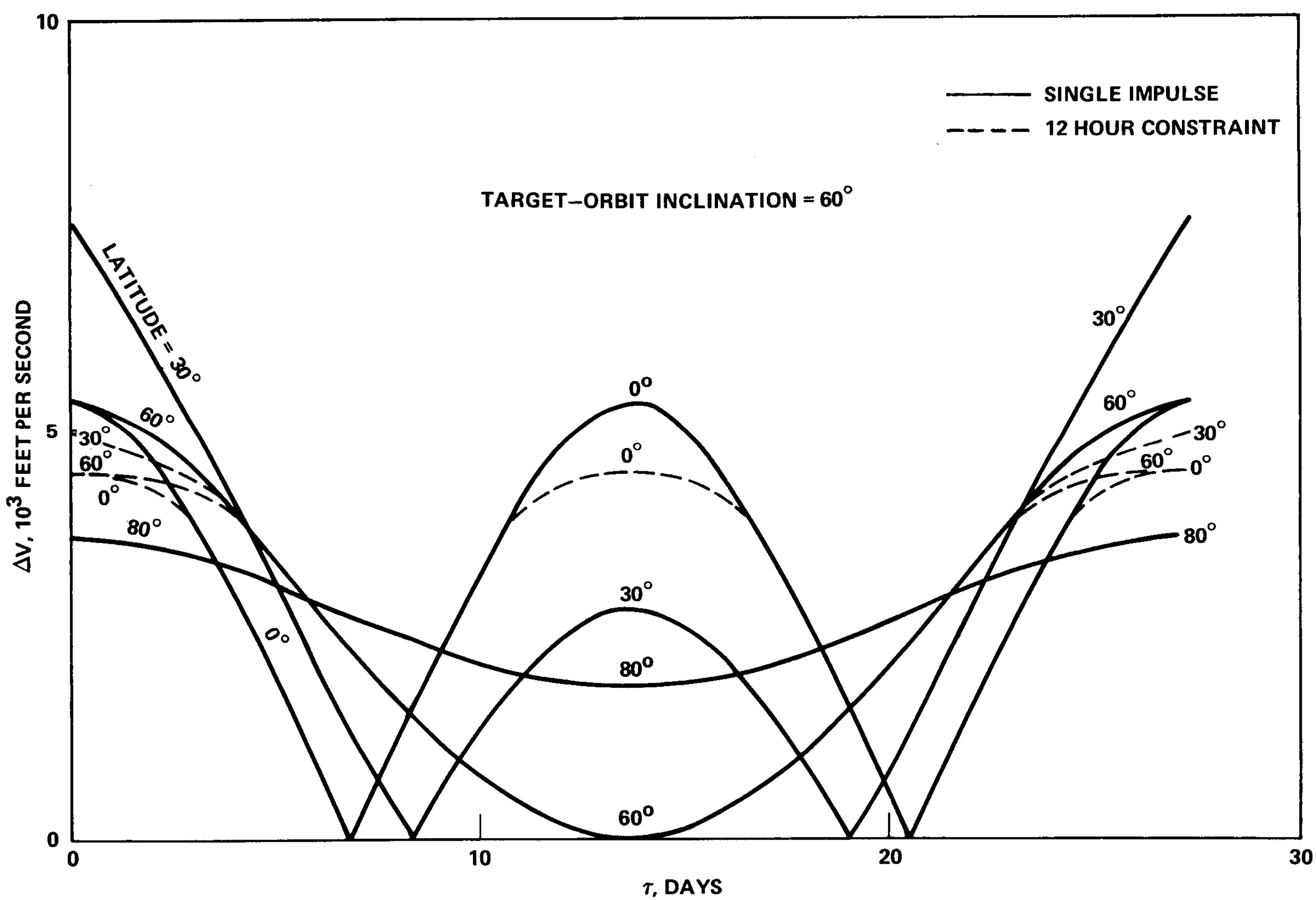


FIGURE 11 HISTORY OF ABORT PLANE-CHANGE ΔV

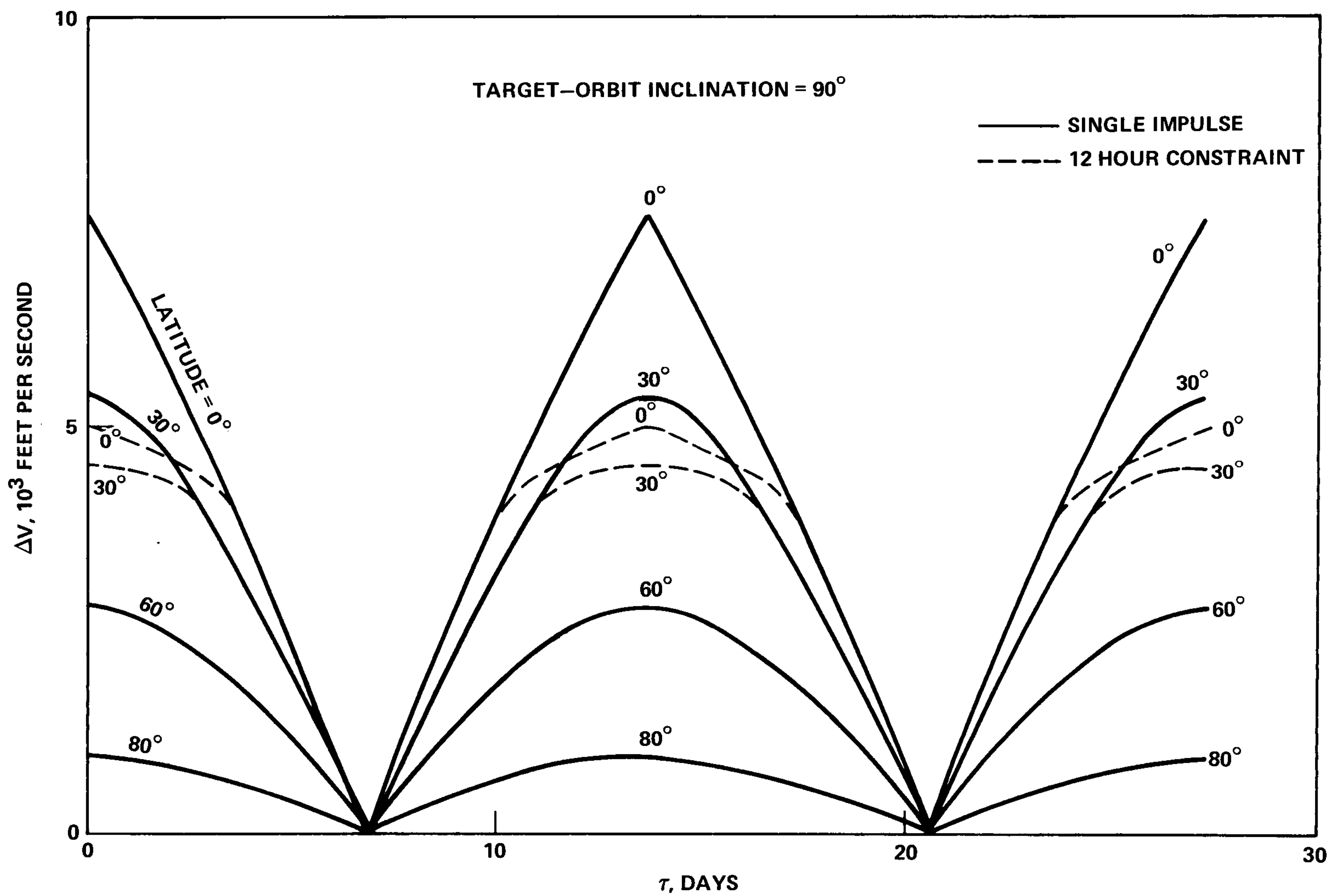
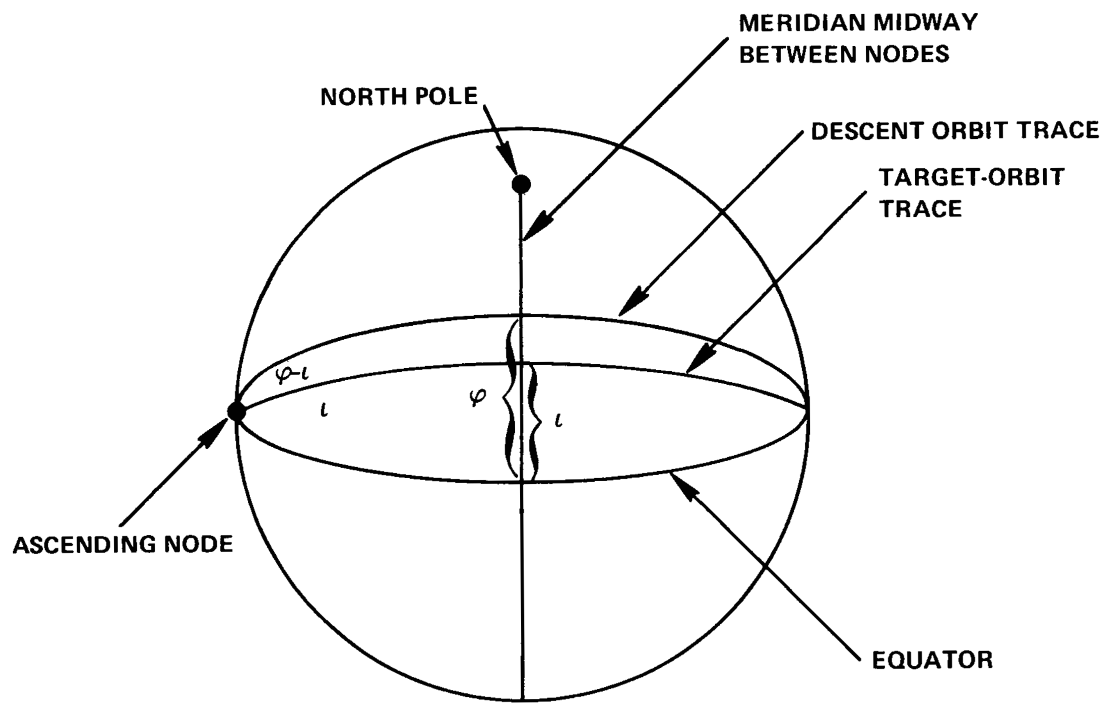


FIGURE 12 HISTORY OF ABORT PLANE-CHANGE ΔV



MERIDIAN MIDWAY BETWEEN NODES
NORTH POLE
DESCENT ORBIT TRACE
TARGET-ORBIT TRACE
φ-ι
ι
φ
ι
ASCENDING NODE
EQUATOR

FIGURE 13

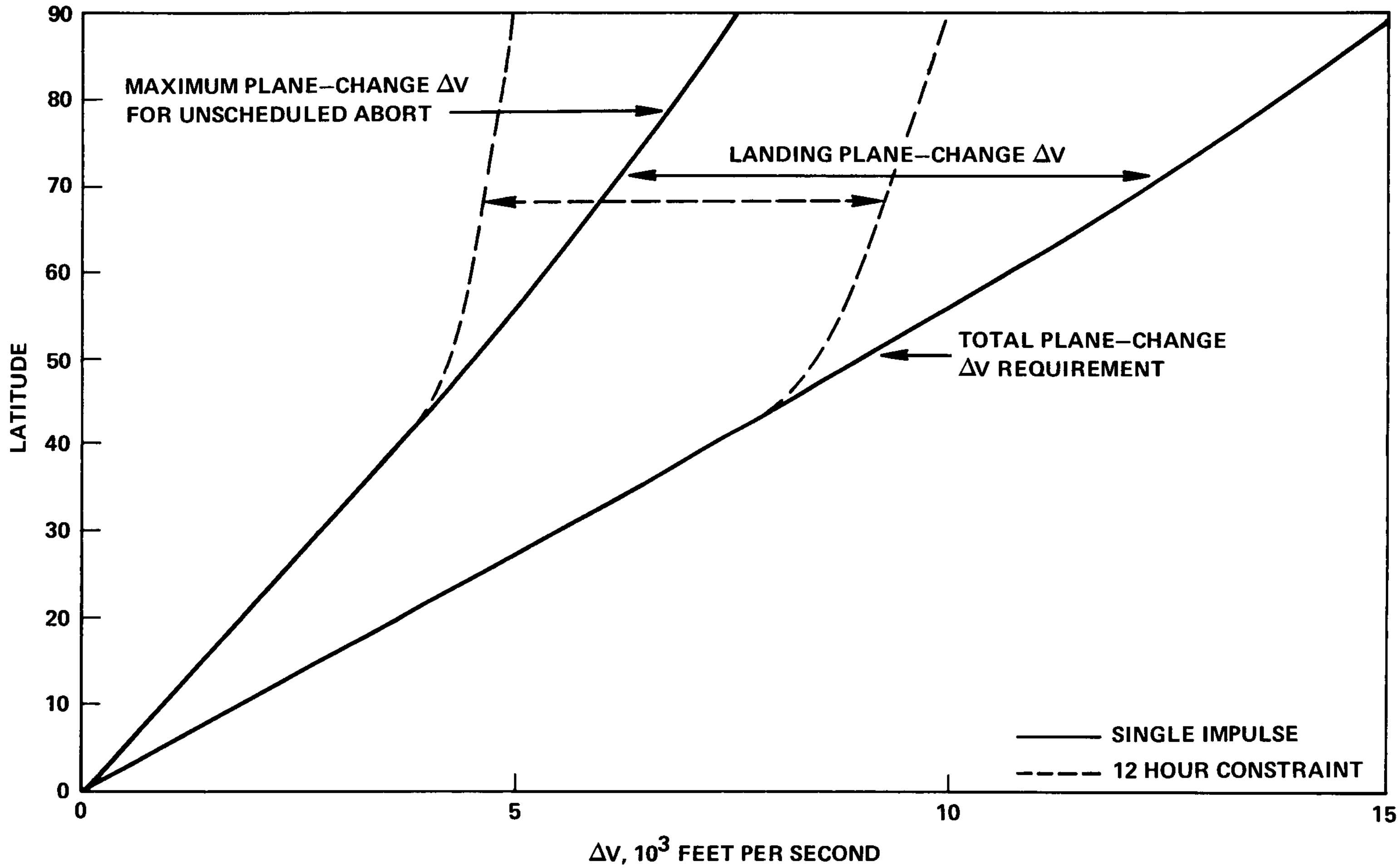


FIGURE 14 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 0°

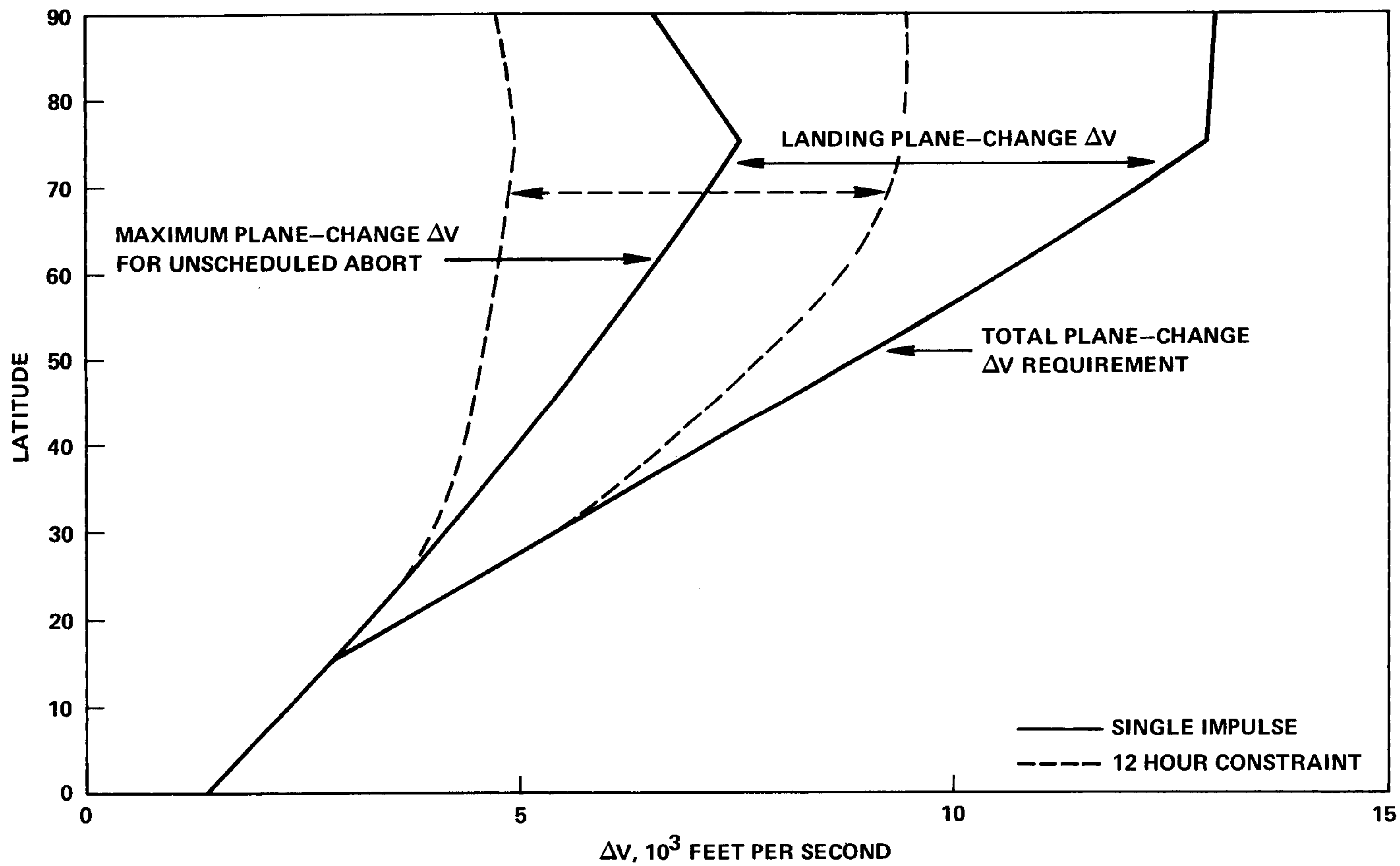


FIGURE 15 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 15°

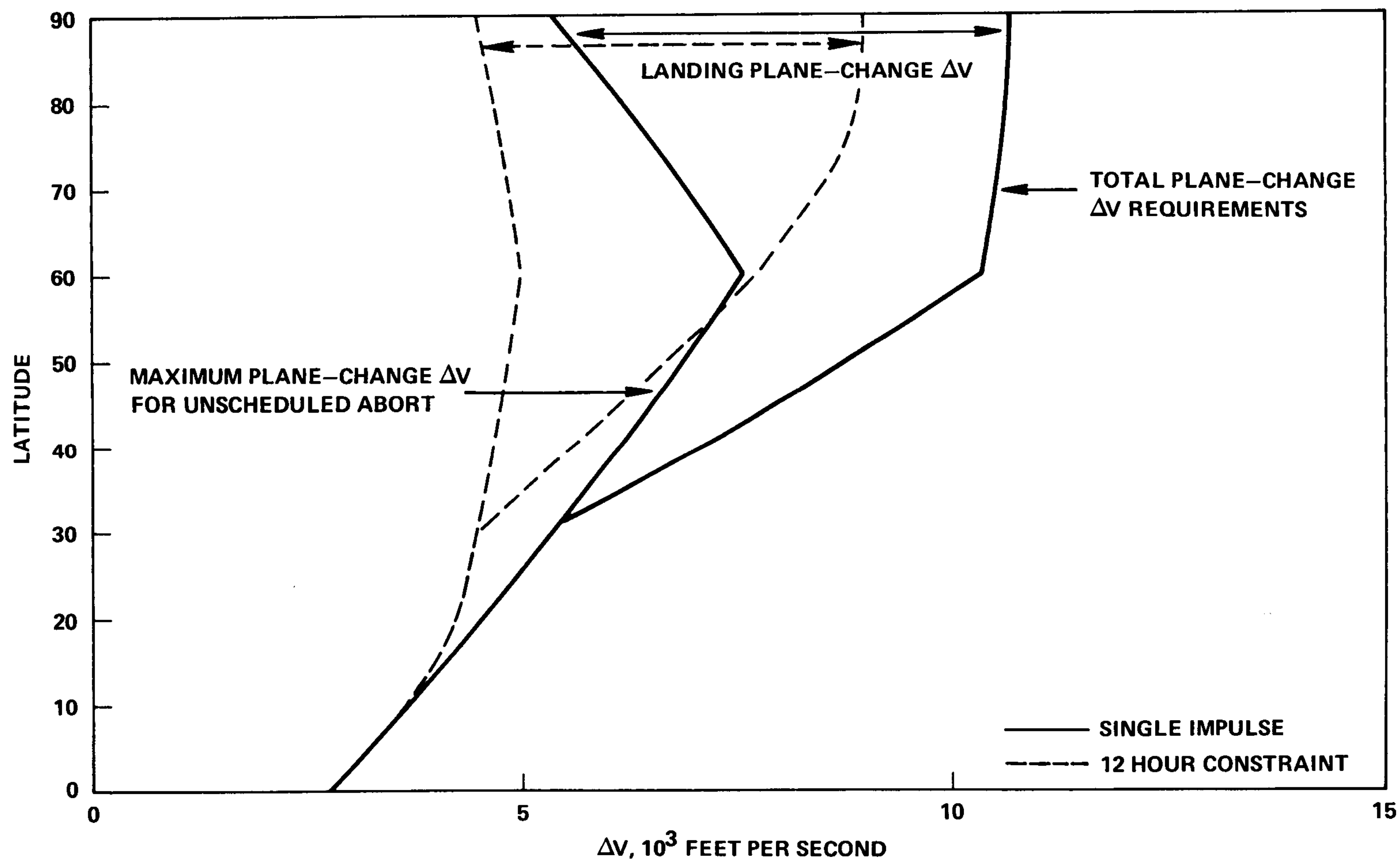


FIGURE 16 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 30°

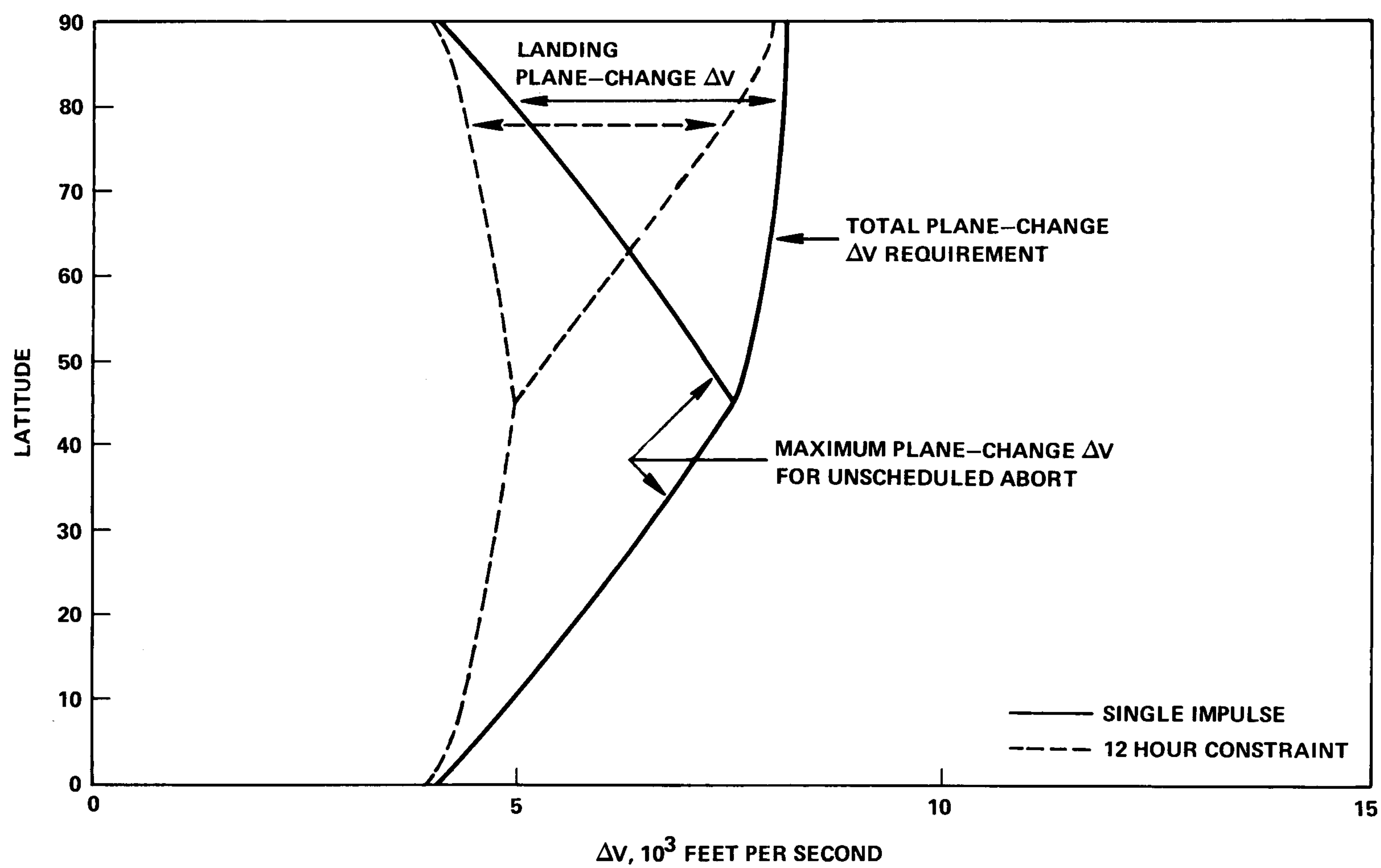


FIGURE 17 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 45°

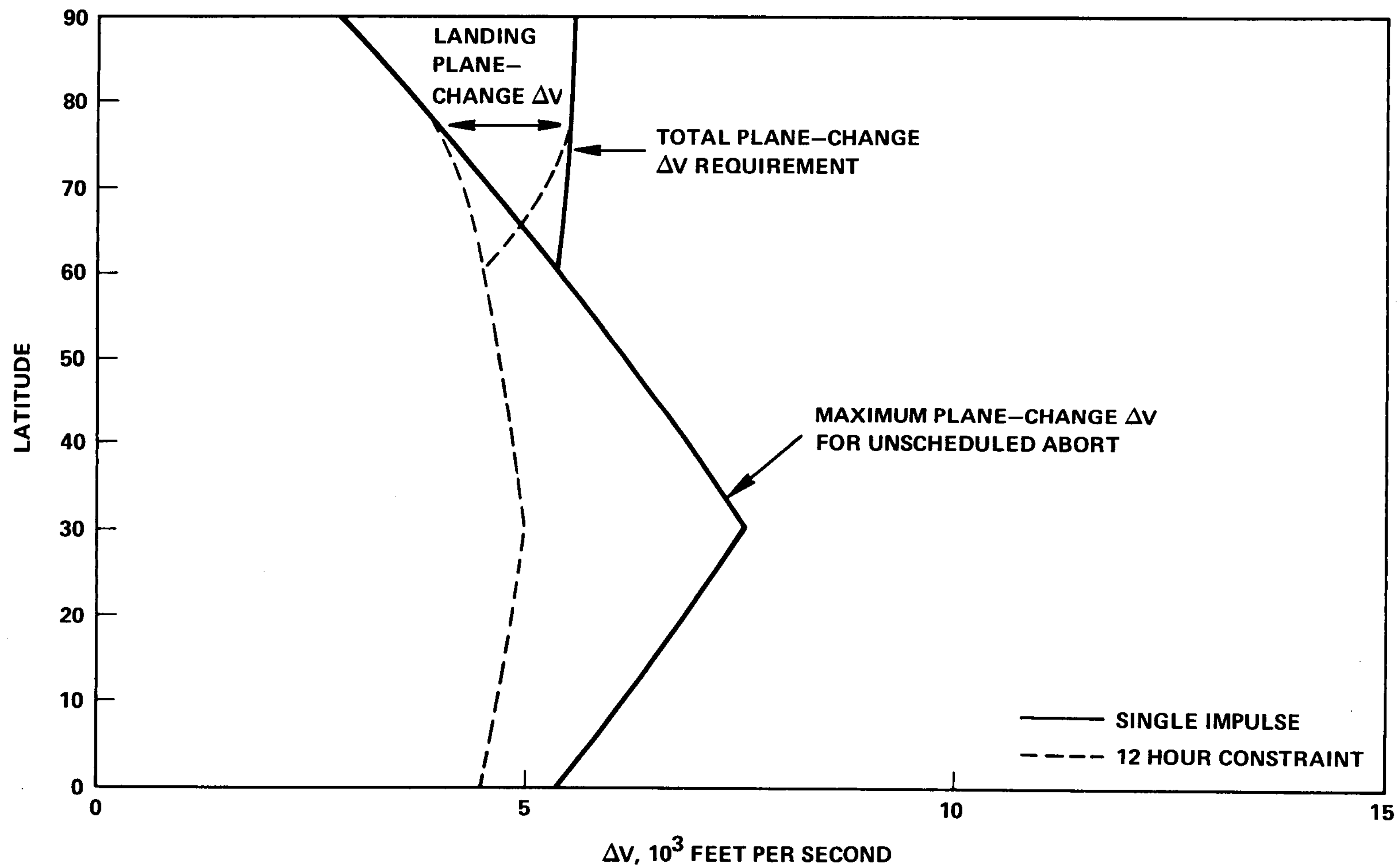


FIGURE 18 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 60°

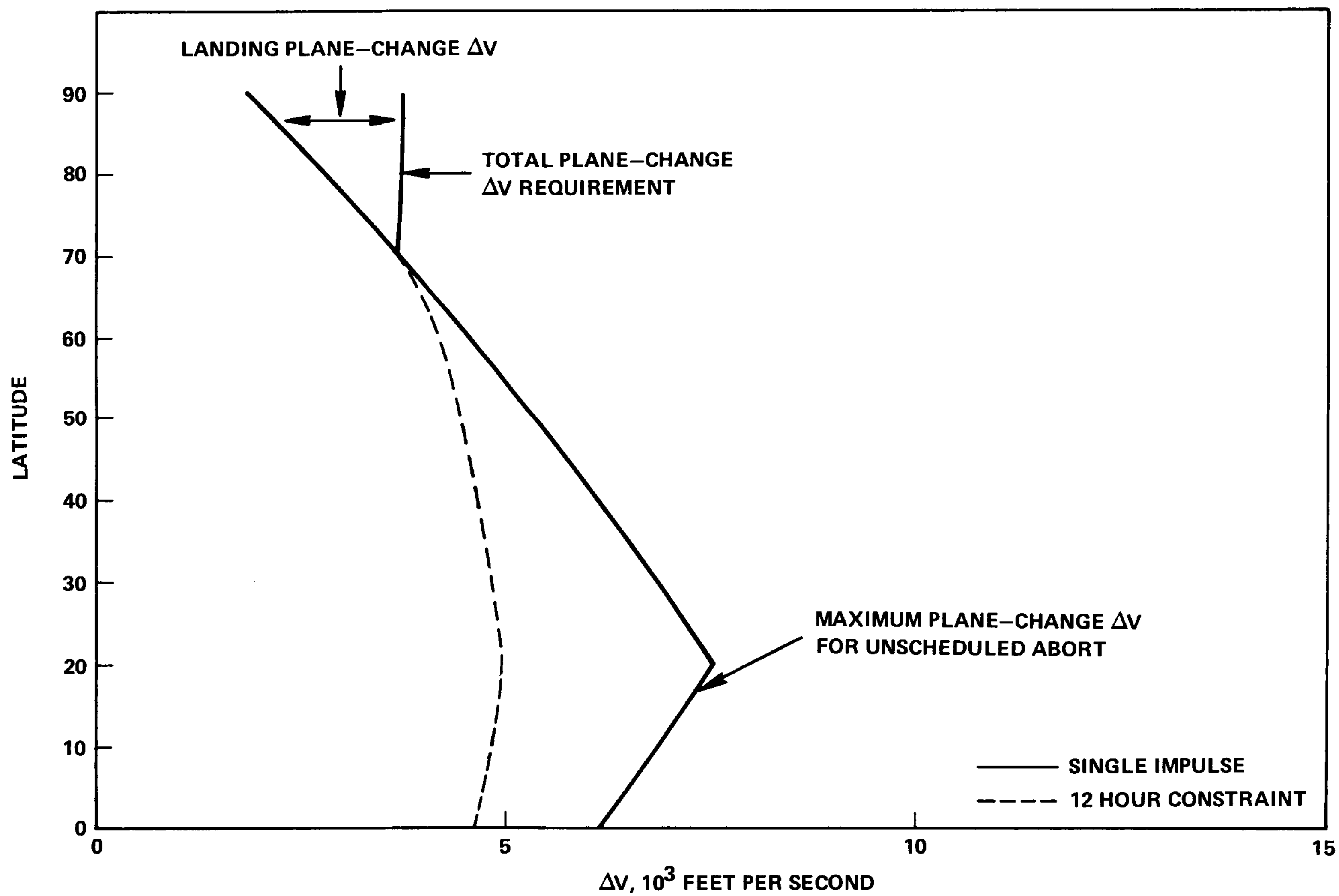


FIGURE 19 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 70°

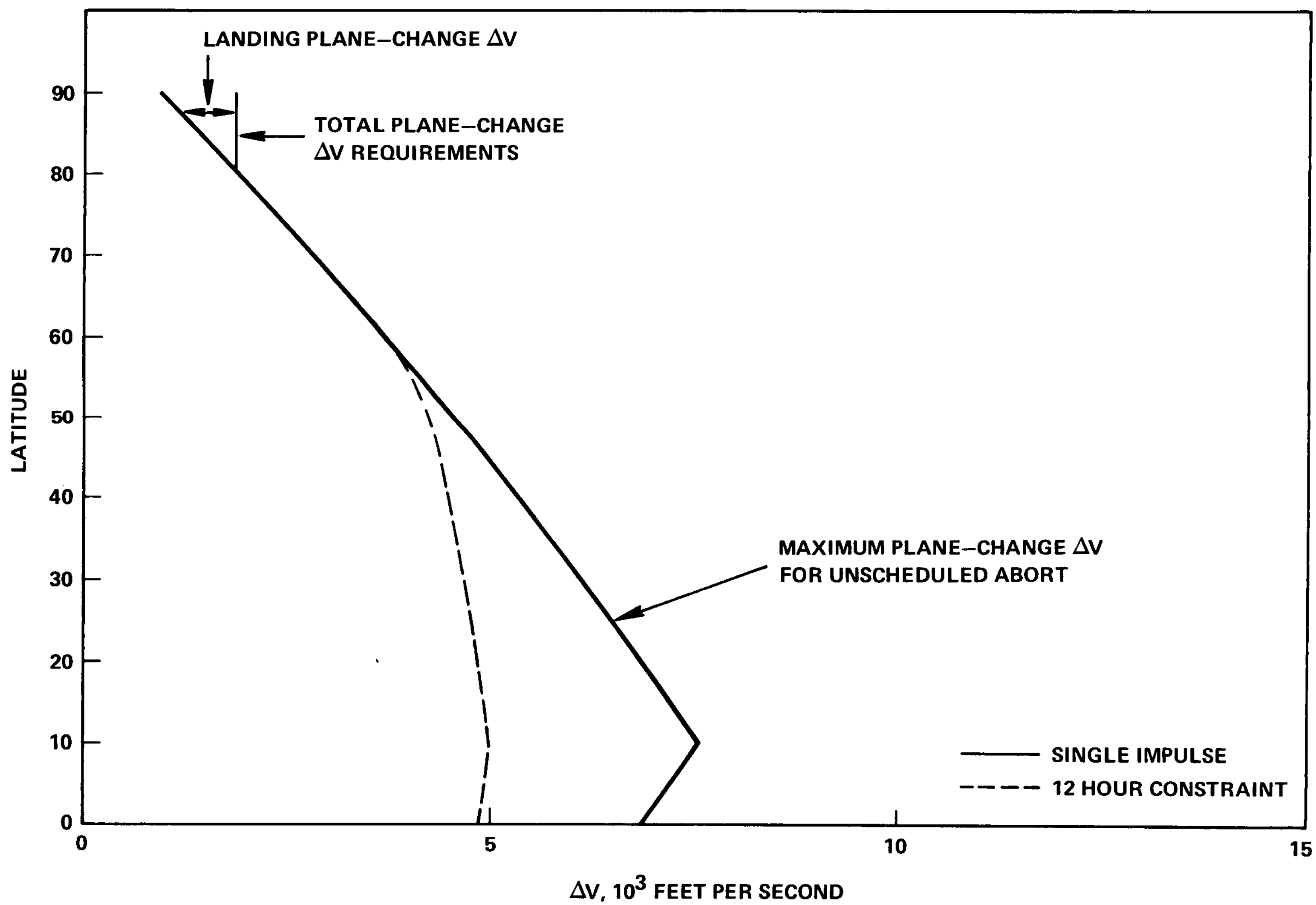


FIGURE 20 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 80°

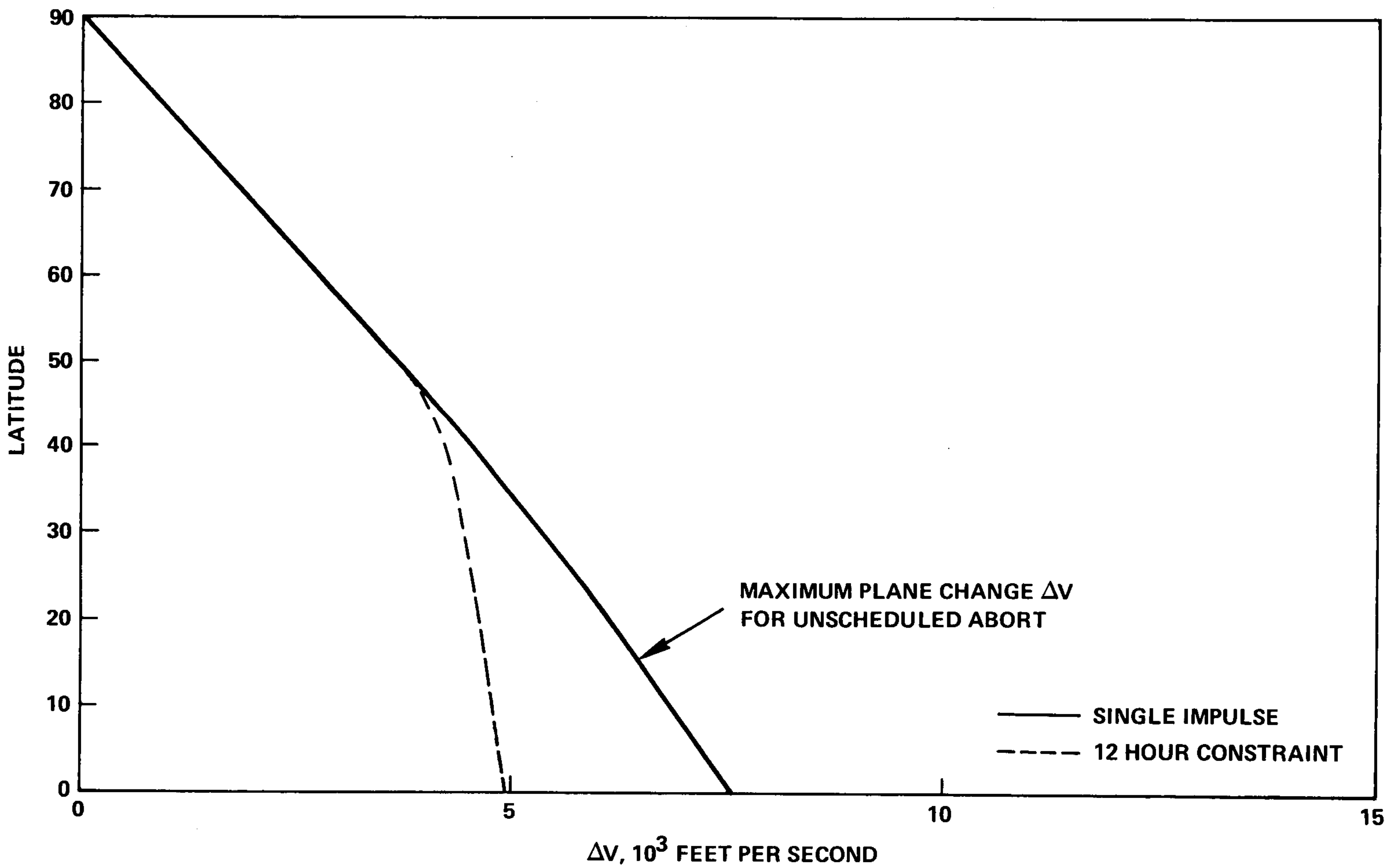


FIGURE 21 - COMBINED ASCENT DESCENT ΔV TARGET-ORBIT INCLINATION = 90°

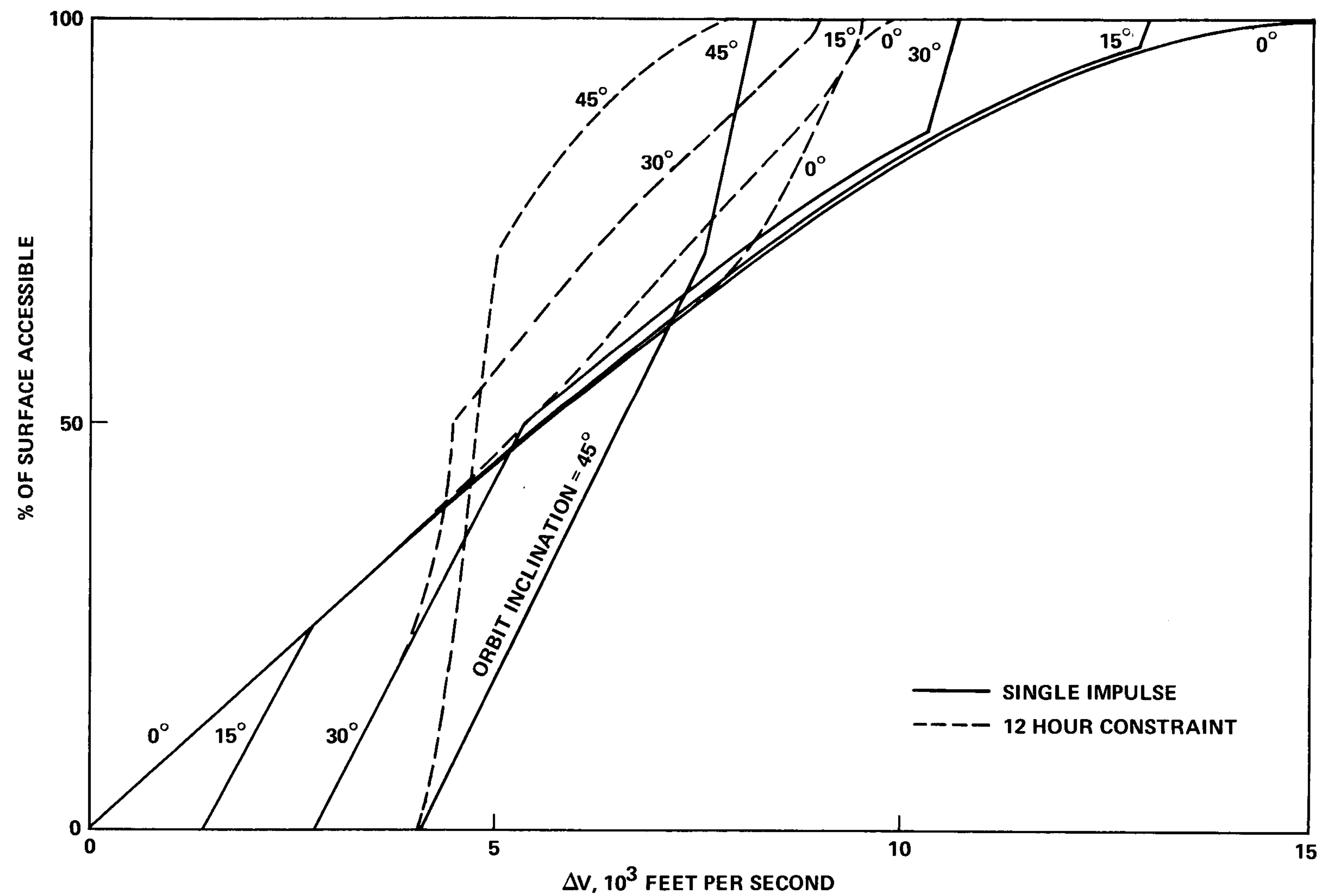


FIGURE 22 PER CENT OF SURFACE ACCESSIBLE VS TOTAL PLANE-CHANGE ΔV CAPABILITY , $\iota \leqslant 45^\circ$

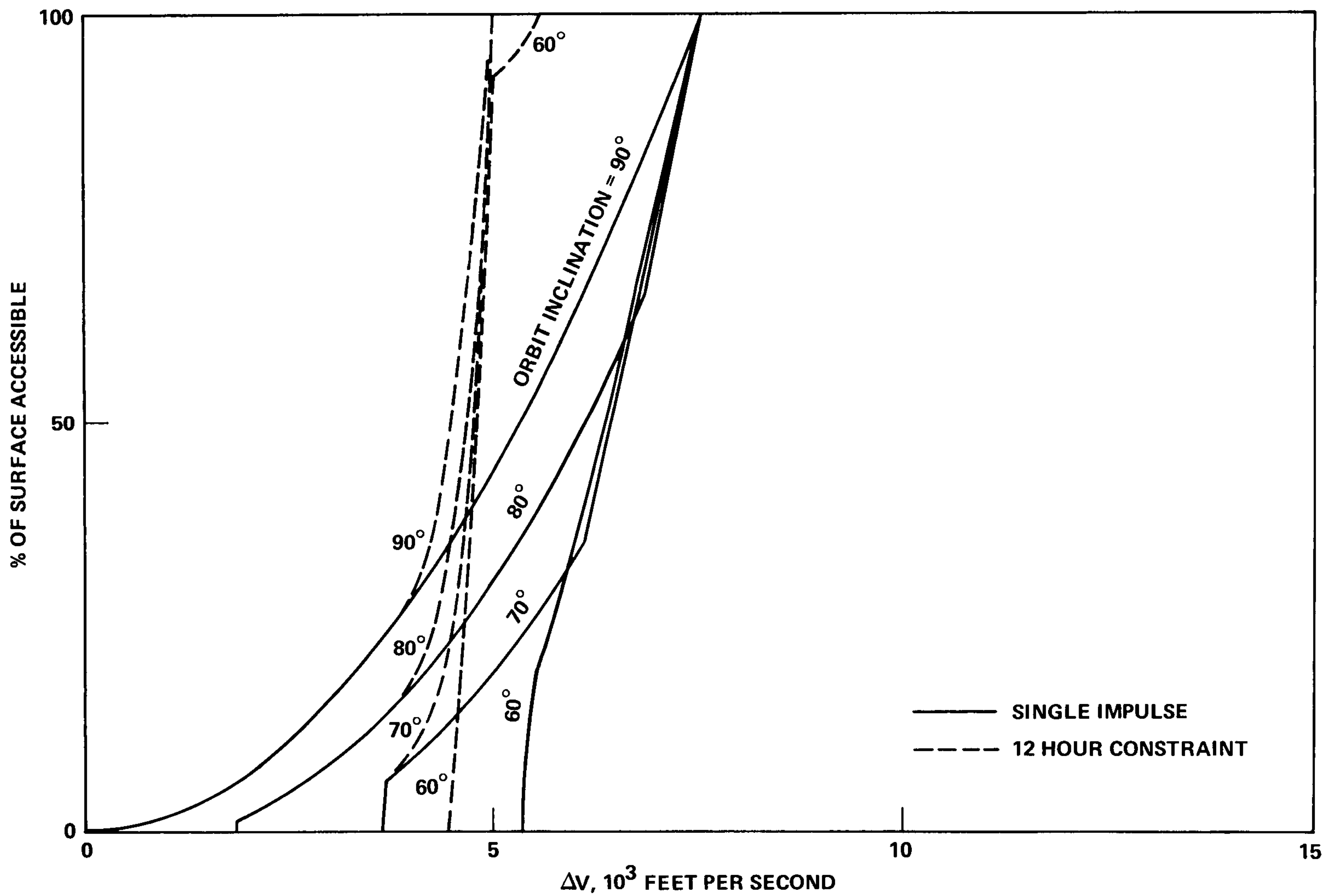


FIGURE 23 PER CENT OF SURFACE ACCESSIBLE VS TOTAL PLANE-CHANGE ΔV CAPABILITY , $45° < \iota \leq 90°$

BELLCOMM, INC.

Subject: Plane-Change Penalty for Unscheduled Abort from the Lunar Surface - Case 105-4

From: A. L. Schreiber

DISTRIBUTION LIST

Complete Memorandum to

NASA Headquarters

W. O. Armstrong/MTX
J. R. Burke/MTE
P. E. Culbertson/MT
L. E. Day/MH
S. S. DiMaggio/MAR
C. J. Donlan/MD-T
E. W. Hall/MTG
T. A. Keegan/MA-2
A. Liccardi/MF
R. L. Lohman/MF
D. R. Lord/MF
A. S. Lyman/MR
L. R. Scherer/MAL
A. D. Schnyer/MTE
A. O. Tischler/RP
M. G. Waugh/MT-1
W. W. Wilcox/RPX
J. W. Wild/MTE

MSC

M. D. Kitchens/HD
A. J. Meyer/HD

MSFC

J. A. Downey/PD-MP-DIR
W. G. Huber/PD-SA-DIR
W. R. Lucas/PD-DIR

Bellcomm, Inc.

G. M. Anderson
D. O. Baechler
A. P. Boysen
D. R. Hagner
E. E. Hillyard
P. F. Long
J. Z. Menard
J. M. Nervik
W. Strack
J. W. Timko
M. P. Wilson
All Members Departments 1011, 1013
Central Files
Department 1024 File
Library

Abstract Only to

J. P. Downs
I. M. Ross
R. L. Wagner